VIBE - Venus In-situ Balloon Explorer

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Summary

The VIBE - Venus In-situ Balloon Explorer - mission is a proposed in-situ analysis of Venus aimed at resolving many unanswered questions about the atmosphere. These questions are aimed at probing whether or not life exists in microbial form in the Venusian atmosphere and probing the history of early Venus. As for the first: It is suspected that life may exist in the clouds on Venus [6][7][10][16][17]. There, the temperature and pressure are like that on Earth, and the stable clouds could contain microbial life. It is additionally known that life exists in Earth clouds, supporting this hypothesis [15]. A likely candidate for this life is the "mode 3" cloud particles in Venus' lower cloud layer that are of an unknown composition. Further evidence for life includes that the atmosphere is in disequilibrium possessing both H_2S and SO_2 which are known to react with one another, suggesting that something is producing the two. It has been proposed that this something is microbial life [17]. The atmosphere also contains COS, which is so difficult to produce inorganically on Earth it is considered an unambiguous indicator of life [10]. In addition to the search for life, this mission aims to study the abundance of noble gasses in the Venusian atmosphere to probe into its early history. Heavy noble gasses such as Xe and Kr will be unlikely to escape Venus' atmosphere on their own, so their abundance will provide information into the history of impacts from celestial bodies on Venus. Measurements of the abundance of Ne will indicate if Venus was formed by the same material as the Earth [3]. The VIBE mission aims to answer these questions by deploying two balloons into the Venusian atmosphere. There, they will perform scientific experiments at varying altitudes aimed at determining the composition of the atmosphere. The balloons will be supported by helium gas sent along with them and will be battery powered. They will carry a Gas Chromatography - Mass Spectrometer, a UV spectrometer, a Nephelometer and an optical camera. The primary goal of this mission is to search for life elsewhere in the solar system. Because of the aforementioned questions about the atmosphere and the fact that the last in-situ observations were done in 1985 by the USSR Vega probe it is believed that Venus is a likely candidate for life. The VIBE mission is well equipped to discover said life or, by resolving these questions without an indication of life, to provide strong evidence against its presence. Whether or not life is found, this mission will be able to answer questions about the early history and formation of Venus which itself is worthy of further investigation.

1 Objectives

- Primarily to examine the possibility of life in the Venusian atmosphere through in-situ analysis
- Secondarily to learn about the history of Venus through its atmospheric composition

2 Background

It is believed that an early Venus had liquid water on its surface for a period of time. During this time it is possible for life to have evolved independently or have been carried there by debris sent from Earth or Mars. While a runaway greenhouse effect has rendered the current surface is incredibly inhospitable with mean surface temperature of 460°C and pressure of 90 atmospheres, this likely took place over long time scales (hundreds of millions of years) [6][17]. It is possible for microbial life to have developed and then retreated to more favorable niches as the surface temperature rose. One such niche is higher in the atmosphere where conditions become quite Earth-like. At ∼50km above the surface, corresponding to the lowest of Venus' three dominant cloud layers, the pressure drops to about 1 atm and the temperatures to ranges where liquid water is possible (25-75°C). In fact, water is estimated at this altitude at a few hundred ppm [17]. Knowing that Earth is host to a variety of microbial life in its clouds suggests that perhaps Venus is the same. Sattler et al. concluded in 2001 that the limiting factor for the persistence of microbial life in clouds on Earth is residence time in the atmosphere [15]. Particles in Venus's clouds have a much longer residence time than those in Earth's clouds. Further, the Venusian clouds are much larger, more continuous, and more stable than Earth clouds, supporting the hypothesis [16].

Now that we have argued that life could possibly exist in the clouds of Venus, we present evidence to suggest that it is there. The first evidence is that the atmosphere contains both H_2S and SO_2. These chemicals are known to react with one another indicating that some process is producing the two [10]. It is possible that the culprit is active volcanism, however H_2S has been measured at a higher level at an altitude of 29-37 km than at an altitude of 0-20 km. This suggests that something is producing H_2S in the atmosphere rather than on the surface, and chemoautotrophic metabolic reactions have been proposed as that something [17]. Further evidence is in the presence of COS in the atmosphere. This chemical is difficult to produce inorganically, and on Earth has been regarded as an unambiguous indicator of life. Again however, active volcanism could be responsible [10]. The vertical distribution of these chemicals must be measured to ascertain what is producing them.

The most probable culprit for life is the large non-spherical particles in the lowest cloud layer known as "mode 3" particles. These are comparable in size to microbes on earth. It has been proposed that these are some substance coated with sulphuric acid, however the inner substance is entirely unknown [7][17].

The greatest obstacles to life in the Venusian clouds are the low pH and the strong presence of UV light. The cloud layers are exceptionally acidic with a pH of 0. While this appears to be a limiting factor for life, acidophilic organisms have been found here on Earth that can grow in such conditions [6]. The high doses of UV radiation poses a more significant problem. To this we note that large regions in the atmosphere possess an unknown absorber of UV light in its atmosphere. It is possible that any potential organisms in the Venusian clouds use this unknown absorber as a shield to protect from the harmful radiation. It has been suggested that elemental sulfur in the form of S_8 is this absorber as S_8 is stable, doesn't react with sulfuric acid and is a strong UV absorber [16]. This absorber is modeled to be most dense at heights of ∼63km or ∼71km which puts it highest cloud layer allowing it to shield most of the atmosphere [13].

In-situ analysis of Venus's atmosphere will provide valuable information to resolve these questions. Such analysis could also provide greater insight into the formation and evolution of the planet and this opportunity should not be passed up. The key to unlocking information about Venus' past lies with the abundance of nobel gasses in its atmosphere. Measurements of isotopic ratios of neon would indicate if Earth and Venus were formed from the same source. The relative abundances of krypton and xenon would yield information on past impact events and the nature of the material that originally formed Venus [3]. Additionally, studying the $^{15}N/^{14}N$ ratio would provide insight into the escape processes in the atmosphere [5].

3 Research Goals

Primary Research Goals -

1. Determine the nature of the "mode 3" cloud particles
2. Determine the nature of the unknown UV absorber
3. Measure the vertical distribution of H_2S, SO_2, and COS

Secondary Research Goals -

1. Measure the abundance of isotopes of Ne
2. Measure the abundance of Xe and Kr
3. Measure the $^{15}N/^{14}N$ ratio

4 Research Approach

The VIBE mission will consist of three components. There will be two balloons meant to descend into the Venusian atmosphere as well as an orbiting module who's purpose is to transport the balloons and relay data transmissions back to the earth. The orbiting module will be the main payload to be launched and upon arrival in orbit around Venus, it will maneuver into position and deploy the two balloons. As it orbits the planet it will act to relay information from the balloons back to the Earth similar to the orbiter in the Viking missions to Mars [9].

The scientific goals will be accomplished by the two Balloons. The first balloon will be deployed into a region of the Venusian atmosphere where the strong UV absorber is present. The second balloon will be deployed into a region where the UV absorber is not present.

The motivation for this is that not only will it make it easier to determine the UV absorbing substance through comparison, but it will allow for a separate analysis of regions shielded by said absorber and regions without such shielding. This will be helpful in determining if the UV shielding provided is a crucial component of the atmosphere or not if, hopefully, microbes are found.

The balloons will conduct measurements at altitudes of ∼71km, ∼63km and ∼50km. The first two heights correspond to the upper regions of the upper and middle cloud layers, and the last corresponds to the lower cloud layer. The first two will allow for observation of the UV absorber, and the latter for observation of the "mode 3" particles [13][19]. It is expected that the balloons will not maintain an exact height but will bob ∼1km up and down throughout the mission. The balloons will be inflated with helium gas shipped along with them to maintain these heights. This is chosen as it was proven successful for the Vega missions and will also allow for the balloons to float in the low pressures of the upper atmosphere [4][11]. They will descend by venting the helium gas into the atmosphere until the proper pressure is reached. The required pressures are 0.04 bar, 0.3 bar and 1 bar for the three listed respective altitudes [18].

The structure of the balloons will also be similar on the USSR's Vega missions. Each balloon will have a flexible envelope to contain the gas, which will support a gondola with scientific instruments. Because of the altitudes VIBE is to probe, extreme heat resistance to protect from the heat at lower levels on Venus need not be factored into the design. Thus the primary restrictions are a material that is strong enough to survive the launch and trip, and a material that is resistant to the acidic nature of the atmosphere. VEGA balloons were constructed of Teflon coated with an acid resistant coating. We propose that the VIBE balloons be constructed of Teflon, fortified by woven carbon fibers to provide durability. For corrosion resistance we propose a two layer gold/silicon-dioxide film [11].

As for power, there will be abundant solar power available for the orbiter. As for the balloons, there are two concerns preventing the use of solar power. First, the Venusian clouds experience a day/night rotation cycle of roughly 5 Earth days [16]. Any balloon equipped with photovoltaic cells would have to store power for 5 days in order to complete more than one rotation. Further, the dense clouds significantly limit the amount of solar power that would be received [12]. Owing to these concerns the VIBE mission will be battery powered. The battery power on the Vega missions lasted for 48 hours, however, with advances in battery technology we believe that a modern balloon mission to Venus could sustain itself for a month [11][4].

The instruments carried by the balloons will be a gas chromatography - mass spectrometer (GC-MS), a UV spectrometer, a nephelometer, and an optical camera. The GC-MS will allow the mission to identify species in the atmosphere to accomplish the first two primary research goals and the secondary research goals. It will require an aerosol collection inlet to allow it to distinguish between gas and particulate substances [19]. Such technology has been proven on Earth for identifying particles in clouds [14]. The UV spectrometer will allow the mission to accomplish the third primary science objective and better survey the Venusian atmosphere from below the cover of the UV absorber. The nephelometer will allow the mission to identify the size and shape of particles in the clouds and assist with the first primary science objective [19]. Finally and optical camera is included for outreach purposes. Data from these instruments will be sent over radio waves to the orbiter when it passes overhead, and then transmitted back to Earth. Radio waves are chosen as they will pass through the Venusian atmosphere (such frequencies were used by the Magellan probe to map the surface from orbit) [8].

5 Relevance to NASA objectives

The study of potential life and the evolution of the planet Venus fit directly into the NASA objectives stated in their 2014 strategic plan. Specifically, the goals of this mission are directly aimed at NASA strategic objective 1.5 - Ascertain the content, origin, and evolution of the solar system and the potential for life elsewhere [1].

Additionally, these goals aim to accomplish stated objectives of NASA's Venus EXploration Analysis Group (VEXAG). Specifically, the VIBE mission will address goal I - Understand atmospheric formation, evolution, and climate history on Venus [2].

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